BATTELLE-TBD-6000 Appendix BB General Steel Industries
ADDENDUM TO
DOSE ESTIMATES FOR BETATRON OPERATIONS WHITE PAPER
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Background

At a meeting of the TBD-6000 working group held on March 15, 2012, the NIOSH white paper on Betatron Operations submitted in January was discussed. Some issues were raised that affect the calculated values in the white paper. This addendum presents recalculated values based on those issues as well as a discussion on some of the other issues raised.

Issues Affecting Estimate

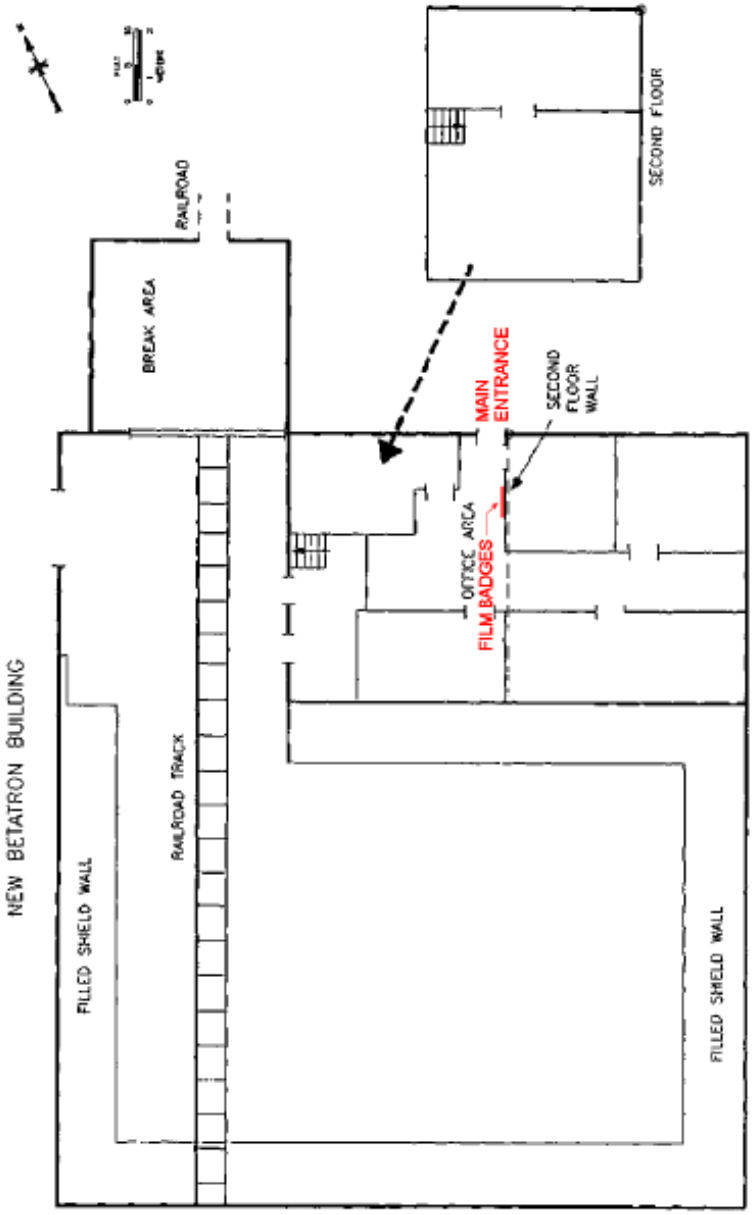
Lead shielding

The white paper included lead shielding in the double leaf door as described in GSI NRC license applications. The new betatron building was first included in license applications in 1968 thus there is no mention of the lead prior to that. The issue was raised that the lead could have been added in 1968 to accommodate a large Co-60 source purchased at that time. With no information about the existence of the lead prior to that, this addendum recalculates the applicable values without the lead present. It should be noted that the lead remains in the building model for the calculations used to verify the building model using the 1971 Co-60 survey data.

Location of Badge Rack

In the original white paper, the film badges were assumed to be stored in the betatron control room. Since a large majority of badges indicated less than 10 mr each week, the dose rate in the control room was assumed to be no more than 10 mr/week. After the white paper was submitted, former workers pointed out that the badges were kept on a badge rack in a hall way outside the betatron control room. This addendum uses the same techniques as discussed in the white paper but assumes the 10 mr/week limit is at the badge rack instead of in the control room. The location of the badge rack was estimated using a drawing from the SC&A review of the white paper. The drawing is included here as Figure 1.

Figure 1 – Drawing of New Betatron Building from FUSRAP documentation with location of badge rack superimposed by SC&A.



Issues Not Affecting Estimate

Some addition issues were discussed that did not require recalculating doses in the white paper. Some of these issues are discussed below.

Betatron Control Room Badges

Dosimetry reports from Landauer through February 6, 1966 included a reading for a badge labeled "Betatron CTL". The white paper interpreted that as betatron control room. Operators indicated they knew of no such badge located in the betatron control room. This addendum to the white paper removes that assumption but that does not affect the calculations. For most operators, the operator badges were either in the badge rack or on their person while they were working in the betatron building. A large majority of the operator badges indicated a reading of less than 10 mr per week. Therefore, the 10 mr/week limit is applied to the badge rack regardless of the location of the Betatron CTL badge.

Control Badges

Normal Landauer practice was to keep a control badge (not to be confused with the Betatron CTL badge) with each batch of film. One of the purposes of the badge is to determine the background radiation levels in the location the personnel badges were kept. That control badge can be used to subtract the background radiation from the other badges and thus determine the actual occupational radiation dose. The control badge dose is included in each weekly dosimeter report from Landauer. For each week of the covered period, the control badges indicated "M" which is recorded for all badges reading less than 10 mrem. It is not clear if Landauer subtracted dose directly in the 1960s or if they subtracted some other value derived from the optical density reading of the film badge. Either way, the value subtracted would have to be directly proportional to the control badge dose. Since the control badges results were reported as "M" each week of the covered period, there would have been no background subtraction performed.

Residual Radiation from Betatron

The white paper explored several possibilities for conflicting information about the magnitude of residual radiation from the Betatron apparatus itself. The white paper concluded the most likely source of reported readings was magnetic interference with the survey instrument. However, the white paper also pointed out that assuming this affect is real would not necessarily increase the

estimated dose. An example calculation to demonstrate this is included at the end of this addendum.

Adjusted Values

Adjustments were made to the white paper calculations as described in the first two issues. In the white paper, dose rates while the betatron is operating were determined in various locations for a variety of shot scenarios. For this addendum, these calculations were redone after eliminating the lead from the double leaf door. An additional dose point at the badge rack was included.

The photon dose estimate for the betatron operators was not based on this analysis so it is unaffected by the recalculated dose rates. The neutron dose however is affected due to a change in the hours for each orientation of the betatron. The dose to the Layout man is also affected. As in the white paper, the Solver add-on in Excel was used to find the maximum weekly dose at the number 10 building within the following constraints:

- Maximum weekly reading at #10 building centerline with equipment tunnel
- Weekly dose at the badge rack equal to 10 mr
- Hours per week (of betatron operation) equal to 69.888 hours
- Hours per week for each orientation greater than or equal to zero

The results of solver calculation was 59.858 hrs per week oriented in the back shot, left, down position and 10.030 hours per week oriented in the railroad, right, up position. Additionally, Solver assigned small amounts of time (less than 0.002 hours) to each of the other orientations.

This resulted in a weekly dose rate in the number 10 building of 226 mr/week from photons. However, this is based on a 168 hour week. Prorating exposures to a 65 hour work week results in an estimated dose of 87.4 mr/week from photons. No significant change of neutron dose rates is expected from the removal of the lead in the double leaf door. However, the hours and orientation of the betatron shots was changed by Solver so the neutron dose to both the betatron operator and the layout man changed.

Table 1 below shows the annual neutron doses to the betatron operator both from the white paper and from this addendum. Table 2 shows the annual doses to the layout man from both the white paper and this addendum.

Table 1 – Betatron Operator Annual Neutron Dose

	January 2012 White Paper	Revised value
Year	Neutron (mrem/yr)	Neutron (mrem/yr)
1953-1960	125	50
1961	132	56
1962	117	43
1963	89	19
1964	82	13
1965	81	12
1966	40	6

Table 2 – Annual Dose to Layout Worker

Year	Photon (mr/yr)	Neutron (mrem/yr)	Skin-WB [a] (rad/yr)	Skin-HF [b] (rad/yr)
January 2010 White Paper				
1953-1965	2030	78	0.540	1.020
1966 [c]	1015	39	0.270	0.510
Revised Values				
1953-1965	4483	148	0.540	1.020
1966 [c]	2241	74	0.270	0.510

a Skin-WB represents the skin of the whole body

b Skin-HF represents the skin of the hands and forearms

c 1966 represents 6 months

Residual Radiation from Betatron

As mentioned earlier, an example calculation is included here to demonstrate the effect of including dose from residual radiation from the betatron apparatus. For this example, it is arbitrarily assumed that 5 mr per week of the badge reading is attributable to this residual radiation.

For the betatron operators, the assumption is then that the film badges are exposed to 5 mr per week from this residual radiation while the operator is wearing the badge. In keeping with that assumption, the dose to the badge from scattered radiation is reduced from 10 mr per week to 5 mr per week to be consistent with actual badge readings. Overall, that results in a higher photon dose but lower neutron dose to the operators as can be seen in Table 3.

Table 3 – Annual Dose to Betatron Operator

Year	Photon (mr/yr)	Neutron (mrem/yr)	Photon (mr/yr)	Neutron (mrem/yr)
	Revised Values in this Addendum		Accounting for betatron residual radiation	
1953-1960	590	50	734	45
1961	620	56	763	51
1962	557	43	702	39
1963	435	19	586	14
1964	406	13	558	9
1965	401	12	554	8
1966 [a]	199	6	275	3

a 1966 represents 6 months

The layout man dose estimate is also affected by this example. This is due to the fact that the hours associated with each betatron shot scenarios had to change to avoid estimating that the badges would always show a dose greater than 10 mr per week. To estimate this dose, Solver was used as before but the weekly dose rate at the badge rack was changed from 10 mr to 5 mr. This resulted in betatron being oriented in the back shot, left, down position for 65.963 hours per week and the railroad, right up position for 3.925 hours per week. That results in 97.4 mr per week at the equipment door in #10 building which is prorated to 37.7 mr per week to the layout man. Neutron dose was 5.34 mrem per week prorated to 2.07 mrem per week. Table 4 shows the layout man annual doses revised in this addendum compared to that obtained in this example.

Table 4 – Annual Dose to Layout Worker

Year	Photon (mr/yr)	Neutron (mrem/yr)	Skin-WB [a] (rad/yr)	Skin-HF [b] (rad/yr)
Revised values in this Addendum				
1953-1965	4483	148	0.540	1.020
1966 [c]	2241	74	0.270	0.510
Results of example calculation				
1953-1965	1995	103	0.540	1.020
1966 [c]	997	52	0.270	0.510

a Skin-WB represents the skin of the whole body

b Skin-HF represents the skin of the hands and forearms

c 1966 represents 6 months

The white paper indicated that both the layout man and the betatron operator dose can be used for employees of GSI and that the most favorable estimate for the case should be used. While accounting for the betatron residual radiation caused higher photon dose for the betatron operator estimate, it caused lower photon doses for the layout man estimate. Since the layout man estimate is the larger of the two, it is the one that would be used in most dose estimates. Thus, it is favorable and more realistic to assume the residual dose rate readings of the betatron are due to magnetic interference.